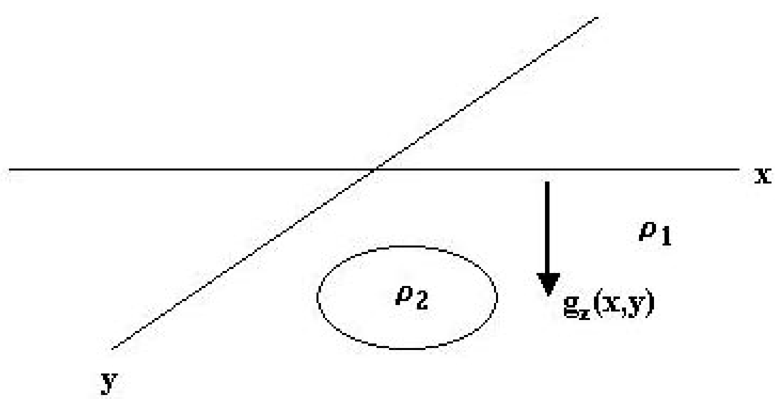
2.6 Interpretation of gravity surveys

- Calculation of excess mass
- The equivalent stratum
- The relative scales of gravity anomalies
- Crustal scale anomalies - isostasy
- Regional anomaly removal – the residual map
- Model fitting and inversion

Calculation of excess mass



Gauss's Law for potential fields can be used to show that the integral of g_z over the horizontal surface above a confined body is related to the excess mass of the body by:

$$\int g_z \, dx \, dy = 2\pi G \, m_{excess}$$

This is about the only objective operation that can be performed without any assumptions on the anomaly of a discrete body. In practice it requires data from which the anomalies of adjacent bodies or structures have been subtracted.

The equivalent stratum

A fundamental statement of non-uniqueness for gravity data is that any observed gravity field on the surface of the earth can be represented exactly by a surface distribution of density given by the following simple formula:

$$g_z(x, y) = 2\pi G \sigma (x, y)$$

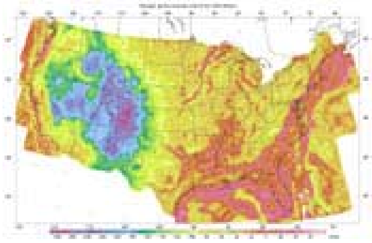
where $\sigma(x, y)$ is a 'surface density' with the dimension gm cm^{-2}. Of course this is a mathematical relation that implies the existence of arbitrary, non-physical, densities but the implications are obvious. A similar formula can be derived for a physical layer in which a lateral variation of volume density can represent the observed gravity. This is a sobering statement about the validity of any gravity interpretation and it illustrates better than any other model the importance of a sound geological model in any interpretation.

The relative scales of gravity anomalies

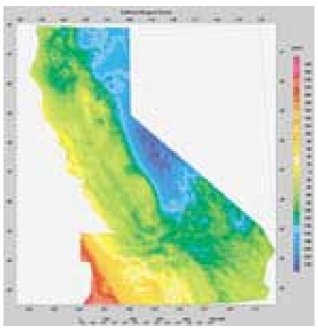
It is observed in field data that there is a roughly linear relationship between the magnitude of an anomaly and its spatial extent or scale. The crust of the Earth is very inhomogeneous and there are large-scale variations on the order of 100 mgals with scale lengths on the order of 100 km. Small features such as buried valleys have anomalies in the 0.1 to 1.0 mgal range with scale lengths of 10's of meters.

Example:

1) US Bouguer Gravity Anomaly Map



2) California Bouguer Gravity Anomaly Map



3) San Francisco Bouguer Gravity Anomaly Map

The basic explanation can be seen in the anomaly of the sphere given above in section 2.4. The maximum anomaly depends on $\Delta\rho\ R^3/z^2$ and since $z > R$ then g_z max is always less than or equal to some constant times R. The anomaly magnitude scales linearly with the size of the feature and its anomaly. (This is fortuitous because it implies that gravity can be acquired with a spatial sampling interval dictated by the scale of the desired target without **aliasing** caused by small-scale anomalies.)

Crustal scale anomalies – isostasy

Major geologic features of the crust, mountain ranges, sedimentary basins, ancient cratons, etc. have pronounced gravity expressions in the Bouguer maps. Mountain belts, and plateau areas in general, have Bouguer anomalies of about -100 mgal per kilometer of uplift. This is because such features are 'floating' on the viscous higher density upper mantle. They have roots of low-density crustal rock which are the source of the negative Bouguer anomaly. This floating equilibrium is called **isostasy**. If perfect isostatic equilibrium is achieved the resulting Bouguer anomaly should be exactly equal to the Bouguer correction that was applied, i.e. $2\pi G\Delta\rho h$. For a typical crustal density of 2.67 we saw in section 2.2 that this is 0.118 mgal/m or 118 mgal/km - just about what is observed.

Regional anomaly removal - the residual map

The anomaly amplitude vs. scale length relationship shows that any desired anomaly will almost inevitably be superimposed on a bigger anomaly with a bigger spatial scale. To interpret the desired feature the larger scale anomaly should be subtracted. This is called removal of the regional anomaly and the remainder is called the residual. The process of isolating the local anomaly is probably the most challenging aspect of gravity interpretation. The continuum of scales makes it very difficult to unambiguously separate a desired (suspected?) feature without knowing the answer! A mathematical statement of the problem is that one has to apply a high pass filter without knowing the spectrum of the target.

In practice the process used is subjective and critically dependent on the geologic model that is assumed. Some of the specific techniques that are employed are

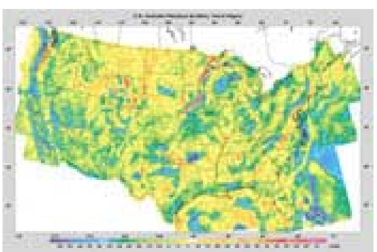
a) subtraction of a plane or higher order polynomial that is fitted to the data outside the area of interest.

b) rigorous filtering of the two-dimensional spatial frequency spectrum with a high-pass, possibly directional, filter.

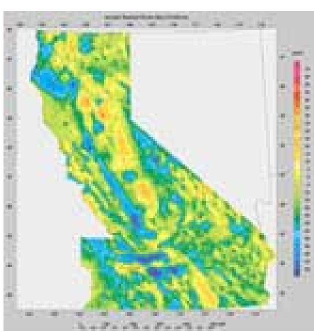
c) wavelet filter.

Example:

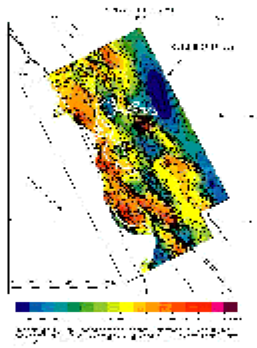
1) Isostatic Residual Gravity Map of the US



2) Isostatic Residual Gravity Map of California



3) Isostatic Residual Gravity Map of the San Francisco Bay Area



This map is from USGS web page

For Additional Information see the map: Roberts, C.W., and Jachens, R.C., 1993, Isostatic residual gravity map of the San Francisco Bay area, California: U.S. Geological Survey Geophysical Investigations Map GP-1006. Available from the USGS--Information Services, Box 25286, Bldg. 810, Denver Federal Center, Denver, CO 80225 303 236-4210.

Model fitting and inversion

The final step in interpretation is the fitting of a model the simulated data from which matches the observed residual Bouguer map. The process is usually carried out interactively - the interpreter alters the parameters of an assumed model until a good visual fit is obtained with the data. In general the results are usually as good as the appropriateness of the assumed geologic model.

In the past few years great advances have been made in automated model fitting. In this process the parameters of an assumed model are varied systematically by an algorithm until the model 'data' matches the observed data in some least squares sense. These are called inversion techniques and they will be discussed in a later section of this course.